

# $B_s$ mesons: semileptonic and nonleptonic decays

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**Abstract.** In this contribution we compute some nonleptonic and semileptonic decay widths of  $B_s$  mesons, working in the context of constituent quark models [? ? ]. For the case of semileptonic decays we consider reactions leading to kaons or different  $J^\pi D_s$  mesons. The study of nonleptonic decays has been done in the factorisation approximation and includes the final states enclosed in Table 2.

## 1 Introduction

The description of CP violation in the Standard Model demands an accurate knowledge of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix. Being the b-sector the one known with lesser precision, a precise quantitative study of the weak decays of  $B$  and  $B_s$  mesons is needed. In this contribution we summarise our studies of the semileptonic decays  $B_s$  into  $K$  and  $D_s$  states, and some of the nonleptonic decays studied in Refs.[? ? ], evaluated in the context of a constituent quark model.

## 2 Semileptonic $B_s \rightarrow K$ decay

The hadronic matrix element for this decay can be parametrised in terms of the form factors  $f_+$  and  $f_0$ . If we neglect the mass of the leptons, only  $f_+$  contributes to the differential decay width

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{192\pi^3} |V_{ub}|^2 \frac{\lambda^{3/2}(q^2, M_{B_s}^2, M_K^2)}{M_{B_s}^3} f_+^2(q^2) \quad (1)$$

with  $G_F$  being the Fermi constant,  $|V_{ub}|$  the modulus of the corresponding CKM matrix element and  $\lambda(a, b, c) = a^2 + b^2 + c^2 - 2ab - 2ac - 2bc$ .

We evaluate the valence quark contribution to the form factor that we supplement with a  $B^*$ -pole one to improve its behaviour at high  $q^2$  values [? ? ]. To extend the above predictions beyond its region

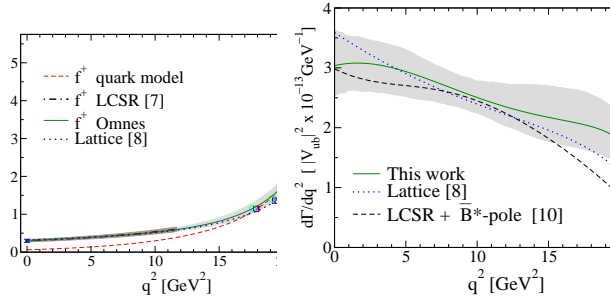
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of applicability (near  $q_{\max}^2$ ), we adopt a multiply-subtracted Omnes dispersion relation [? ? ? ? ], and we take

$$f^+(q^2) \approx \frac{1}{M_{B^*}^2 - q^2} \prod_{j=0}^n [f_+(q_j^2)(M_{B^*}^2 - q_j^2)]^{\alpha_j(q^2)}, \quad \alpha_j(q^2) = \prod_{k=0, k \neq j}^n \frac{q^2 - q_k^2}{q_j^2 - q_k^2} \quad (2)$$

for  $q^2 < s_{th} = (m_{B_s} + m_K)^2$  and where the different  $q_j^2 \in ]-\infty, s_{th}[$  are the different subtraction points. The values of the  $f_+$  form factor at the subtraction points are taken as free parameters that we fit to our quark model results (valence plus  $B^*$ -pole) at high  $q^2$  and previous light cone sum rules (LCSR) results in the low  $q^2$  region [? ]. We take the subtraction points at  $q^2 = 0, q^2 = \frac{q_{\max}^2}{3}, q^2 = \frac{2q_{\max}^2}{3}$  and  $q^2 = q_{\max}^2$ . In the left panel of Fig. 1 we compare the  $f_+$  form factor obtained in our combined



**Figure 1.** Left panel: Comparison of the different approaches to the  $f_+$  form factor. Right panel: Differential decay width calculated with a 68% confidence level band obtained with our fitting procedure

approach with the ones calculated using LCSR techniques [? ] and lattice QCD [? ]. The latter are an extrapolation of the lattice points obtained in Ref. [? ] which are also shown. In the right panel, we plot the differential decay width. We compare our results with the ones in Ref. [? ], obtained in a LCSR+ $B^*$ -pole calculation, and in Ref. [? ], obtained in lattice QCD. In both panels we also include a 68% confidence level band for our predictions. The total decay width that we get is  $\Gamma(B_s \rightarrow K l^+ \nu_l) = (5.47^{+0.54}_{-0.46})|V_{ub}|^2 \times 10^{-9} \text{ MeV}$ . This is to be compared with the results  $(4.63^{+0.97}_{-0.88})|V_{ub}|^2 \times 10^{-9} \text{ MeV}$  [? ], where we have propagated a 10% uncertainty in the form factor, and  $(5.1 \pm 1.0)|V_{ub}|^2 \times 10^{-9} \text{ MeV}$  [? ]. The three estimates are compatible within uncertainties. More details are given in Ref. [? ].

### 3 Semileptonic $B_s \rightarrow D_s^{(*)}$ decays

We have considered the semileptonic decays of  $B_s$  meson into  $D_s^{(*)}$  states with  $J^\pi$  quantum numbers  $0^-, 0^+, 1^-, 1^+, 2^-$  and  $2^+$ . The form factor decomposition required for each channel can be found in Ref. [? ]. We have adopted the helicity formalism of Ref. [? ] to compute the contraction of the leptonic and hadronic tensors. Expressions for the helicity amplitudes can be found in Ref. [? ].

In Table 1 we show our results for the branching ratios. As shown in Table V of Ref. [? ] the results of this work are in good agreement with those from Ref. [? ], obtained in a relativistic quark

**Table 1.** Branching fractions for the indicated decay channels, in percentage.

$M'$	$l = e, \mu$	$l = \tau$
$D_s^+$	2.32	0.67
$D_{s0}^{*+}$	0.39	0.04
$D_s^{*+}$	6.26	1.53
$D_{s1}^+(2460)$	0.47	0.04
$D_{s1}^{*+}(2536)$	0.32	0.03
$c\bar{s}(2^-)$	$9.2 \cdot 10^{-3}$	$2.0 \cdot 10^{-4}$
$D_{s2}^{*+}$	0.44	0.03

model approach. The agreement is also good with the quark model calculation of Ref. [? ]. Our results for decays into orbitally excited final  $D_s^*$  mesons agree with our previous results from Ref. [? ], though in that work the potential model that has been used was much more sophisticated. Our results also compare well to the sum-rules calculation of Refs. [? ? ], while the result of Ref. [? ] is lower by a factor of two. The same happens if we compare with the results of Ref. [? ] or Ref. [? ]. In Ref. [? ] we also check our results against Heavy Quark Symmetry predictions.

#### 4 $\bar{B}_s \rightarrow c\bar{s}M_F$

We have also calculated the decay width for two-meson nonleptonic reactions  $\bar{B}_s \rightarrow c\bar{s}M_F$  where  $M_F$  is a light pseudoscalar or vector meson. These decays correspond to a  $b \rightarrow c$  transition at the quark level. These transitions are governed, neglecting penguin operators, by the effective Hamiltonian of Eq. (53) of Ref [? ]. See Refs. [? ? ] for further details. We shall work in the factorisation approximation, i. e., the hadron matrix elements of the effective Hamiltonian are evaluated as a product of quark-current matrix elements. One of these is the matrix element of the  $B_s$  transition to one of the final mesons, while the other is determined by the decay constant of the other meson. In Table 2 we compare our calculations with previous results and experimental data when available. More results are shown in Ref. [? ].

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	This work	[? ]	[? ]	[? ]	[? ]	Experiment [? ]
$\bar{B}_s \rightarrow D_s^+ \pi^-$	0.53	0.35	0.5	$0.27^{+0.07}_{-0.03}$	$0.17^{+0.07}_{-0.06}$	$0.32 \pm 0.4$
$\bar{B}_s \rightarrow D_s^+ \rho^-$	1.26	0.94	1.3	$0.64^{+0.17}_{-0.11}$	$0.42^{+1.7}_{-1.4}$	$0.74 \pm 0.17$
$\bar{B}_s \rightarrow D_s^+ K^-$	0.04	0.028	0.04	$0.021^{+0.002}_{-0.002}$	$0.013^{+0.005}_{-0.004}$	
$\bar{B}_s \rightarrow D_s^+ K^{*-}$	0.08	0.047	0.06	$0.038^{+0.005}_{-0.005}$		
$\bar{B}_s \rightarrow D_{s0}^{*+} \pi^-$	0.10	0.09	$0.052^{+0.25}_{-0.021}$			
$\bar{B}_s \rightarrow D_{s0}^{*+} \rho^-$	0.27	0.22	$0.013^{+0.06}_{-0.05}$			
$\bar{B}_s \rightarrow D_{s0}^{*+} K^-$	0.009	0.007	$0.004^{+0.002}_{-0.002}$			
$\bar{B}_s \rightarrow D_{s0}^{*+} K^{*-}$	0.16	0.012	$0.008^{+0.004}_{-0.003}$			
$\bar{B}_s \rightarrow D_s^{*+} \pi^-$	0.45	0.27	0.2	$0.31^{+0.03}_{-0.02}$		$0.21 \pm 0.06$
$\bar{B}_s \rightarrow D_s^{*+} \rho^-$	1.35	0.87	1.3	$0.9^{+1.5}_{-1.5}$		$1.03 \pm 2.6$
$\bar{B}_s \rightarrow D_s^{*+} K^-$	0.04	0.021	0.02	$0.024^{+0.002}_{-0.002}$		
$\bar{B}_s \rightarrow D_s^{*+} K^{*-}$	0.08	0.048	0.06	$0.056^{+0.006}_{-0.007}$		
$\bar{B}_s \rightarrow D_{s1}^+ (2460) \pi^-$	0.15	0.19				
$\bar{B}_s \rightarrow D_{s1}^+ (2460) \rho^-$	0.36	0.49				
$\bar{B}_s \rightarrow D_{s1}^+ (2460) K^-$	0.012	0.014				
$\bar{B}_s \rightarrow D_{s1}^+ (2460) K^{*-}$	0.020	0.026				
$\bar{B}_s \rightarrow D_{s1}^+ (2536) \pi^-$	0.07	0.029				
$\bar{B}_s \rightarrow D_{s1}^+ (2536) \rho^-$	0.19	0.083				
$\bar{B}_s \rightarrow D_{s1}^+ (2536) K^-$	0.0054	0.0021				
$\bar{B}_s \rightarrow D_{s1}^+ (2536) K^{*-}$	0.01	0.0044				
$\bar{B}_s \rightarrow (2^-)^+ \pi^-$	$7.1 \cdot 10^{-5}$					
$\bar{B}_s \rightarrow (2^-)^+ \rho^-$	0.0047					
$\bar{B}_s \rightarrow (2^-)^+ K^-$	$5.2 \cdot 10^{-6}$					
$\bar{B}_s \rightarrow (2^-)^+ K^{*-}$	$2.2 \cdot 10^{-8}$					
$\bar{B}_s \rightarrow D_{s2}^{*+} \pi^-$	0.1	0.16				
$\bar{B}_s \rightarrow D_{s2}^{*+} \rho^-$	0.27	0.42				
$\bar{B}_s \rightarrow D_{s2}^{*+} K^-$	0.008	0.012				
$\bar{B}_s \rightarrow D_{s2}^{*+} K^{*-}$	0.016	0.022				

**Table 2.** Branching ratios for the decays above.